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Five years continuous recording of daylight illumination at Kew Observatory

by

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Summary

The intensity of illumination on a horizontal surface has been recorded continuously at Kew Observatory since January, 1947. In this paper, the various errors inherent in the measurements are considered; the methods of correcting the basic tabulations are demonstrated; and the corrected data are presented in the form of hourly means for 10 day periods.

Examples of the diurnal variation of illumination on cloudless and overcast days are given, and the frequency distribution of illumination at noon for selected months is indicated. The relation between illumination and solar (sun + sky) radiation is discussed.

1. Introduction.

(a) Some remarks on photometry. The object of the work to be described is the continuous measurement of the luminous flux through a horizontal surface fully exposed to sun and sky, by instrumental photometry of a white diffusing surface. The illumination of a surface is measurable by visual comparison with a similar surface illuminated by a standard source. The ultimate standard of luminous intensity is a full (black body) radiator at the temperature of solidifying platinum (1), (2), but in practice it is realised by means of standard lamps.

A standard eye has been specified by the International Commission on Illumination from the results of experiments on numerous observers (3). This specification states the relative sensitivity of the eye, throughout the spectrum, to a given quantity of monochromatic radiation. Although the sensitivity function varies with intensity at lower levels of illumination, it is constant in the range with which this report is concerned (photopic vision). This puts the comparison of illumination due to sources of different colours on a sound basis, and facilitates instrumental rather than visual photometry, it being merely necessary to ensure that the relative response of the intrument is the same as that of the I.C.I. eye throughout the spectrum.

The unit of illumination is the lux, the illumination produced by a source of unit candle power (1 candela) at a distance of 1 metre, where 1 candela is one sixtieth of the luminous intensity per sq. cm. of the standard radiator. For daylight illumination, the kilolux is a convenient unit. In the present work, mean hourly values in kilolux have been tabulated and totals of these have been used. The tabulated values are therefor in kilolux-hours, a convenient rather than physically significant unit.

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(b) History of the Kew recorder. The recording of daylight illumination at Kew Observatory was planned by Dr. J.M. Stagg in 1939, and the project was revived in 1946. Continuous records had been maintained at Plymouth for some years by Atkins (4) using a vacuum sodium cell, and experiments in continuous recording at the National Physical Laboratory (5) had involved the use of a selenium cell. In deciding on the arrangement to be used at Kew, valuable advice was given by Dr. J.S. Preston of the N.P.L. and the final choice was that of a selenium photocell combined with a specially constructed correcting filter, exposed below a diffusing surface of pot opal glass which was roughened on the upper side. The filter was designed to match the mean response curve of the class of cell used, to allow replacement of the cell with the least possible loss of precision.

For the first two years, the instrument which will be referred to as the Mk.I was in use; this was then replaced by that known as the Mk.II. The change was made chiefly for convenience in handling and maintenance, but it was later realised that systematic errors of calibration had been reduced by the change.

As experience was gained, appreciation of errors in the method of measurement and calibration increased; but most of these were not fully apparent until an examination of the first five years of recording had been made. It was found possible to correct the tabulated mean values retrospectively, and much of this report is taken up with a discussion of the imperfections of the measurements and of the corrections which were applied.

2. Description of the instruments.

(a) Mark I instrument. This, the original version of the recorder, was used throughout 1947-48. As shown in Fig. 1(a), the cell and filter unit was mounted within an airtight metal box with a glass cover. This box was set inside a louvred screen, at the top of which was a sheet of diffusing pot opal glass, roughened on the upper side. This, in turn, was protected by a clear, hemispherical glass dome. The air within the box containing the cell was kept dry by silica-gel which was changed once a month at times of calibration.

(b) Mark II instrument. After 1948, the more compact Mk.II version came into use. As shown in Fig. 1(b), the pot opal glass now directly surmounts the inner box which contains the cell and filter unit. The hemispherical glass dome is mounted as an integral part of a new outer case which, in turn, is covered by the white louvred screen.

(c) Recorder circuit. The current output against intensity of illumination curve, for the type of photocell used, depends on the load resistance. To obtain a nearly linear relation, this resistance is best fixed at about 200 ohms. The output from the cell is led away to a Cambridge thread-recorder which is combined with a network of shunt and series resistors, arranged in such a way as to allow three sensitivities (for different times of the year) while keeping the load resistance constant at 200 ohms.

(d) Protection of the photocell from excessive exposure. Since excessive illumination, and consequent high current output, would impair the performance of the photocell, the geometry of the Mk.I instrument was designed to reduce the incident daylight flux by a factor of about ten. This is achieved partly by means of the dimensions and distances of the apertures and partly by the losses due to reflection at the hemispherical glass dome, the diffusing plate, the inner glass cover and the filter.

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In the case of the Mk.II instrument, the photocell is rather closer to the diffusing plate, and an additional restricting diaphragm is inserted underneath and touching the plate, in order to limit the aperture. In this way, the maximum permissible output current is not reached under working conditions.

(e) Response curves of instrument and standard eye. Fig. 2 shows the close approximation of the sprectral sensitivity curve of the cell and filter, as determined at the N.P.L., to that of the I.C.I. standard eye, which represents the normal human eye adapted to conditions of high luminance (photopic vision).

3. Standardisation of the recorder.

(a) Method. The difficulty is that it is not possible to produce a known illumination comparable in intensity with natural daylight. It is easy, however, to produce, on the cell and filter unit alone, a known illumination comparable with that to which it is subjected when the diffusing plate is exposed to full daylight, and the unit is in its normal position inside the recorder.

The combined cell and filter unit is therefore mounted vertically at one end of a photometry bench. A 100 watt lamp is used to obtain a response curve at various illuminations up to the maximum intensity expected, intensity being judged by cell output. Any marked non-linearity in the response curve, (output being plotted against the inverse square of distance), leads to replacement of the photocell.

In the second stage of calibration, the complete recorder, again mounted vertically, is exposed to a 1000 watt standard lamp at one or two points on the photometry bench, and the cell output noted. In this way, the scale of illumination for the first curve is computed in absolute units (kilolux). Allowance is made for any stray light by alternately shading and unshading at a point midway between the lamp and the pot opal disc of the recorder.

According to the maximum intensity expected during the month to which the calibration applies, the best straight line is drawn through the experimental points, within this range, on the first curve. The factor is then calculated in kilolux per division of the thread-recorder chart, for whichever of the three sensitivities is to be used.

(b) Standard lamps. Two 1000 watt, 110 volt, tungsten filament projector lamps, calibrated at the National Physical Laboratory in 1947, and recalibrated in 1952, have been used as the reference sources throughout the period. As the two calibrations agreed to within 2% and the quoted accuracy is given as $\pm 2\%$, these standards are taken to have remained constant in brightness. The lamps are slightly under-run at 100 volts, when the horizontal candle power is about 2200 C.P.

4. Systematic errors of Standardisation.

(i) From the smoothness of the calibration curves, and the fact that these pass through the zero point, it is concluded that errors of measurement, and errors resulting from stray light and rapid uncompensated voltage fluctuations may be neglected. Allowance must be made, however, for the polar diagram of the lamps and the variation of illumination over the area of the opal plate. In the case of the Mk.I instrument, the diameter of this plate is six inches, involving a difference of 6% between the mean intensity and that at the centre of the opal disc. In the Mk.II instrument, the limiting diaphragm has a diameter of two inches, involving a correction of -1%.

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(ii) There is also a small systematic correction for the difference in quality of the calibrating light and daylight, since the combined cell plus filter response curve is not exactly that of the I.C.I. eye. The filter matches the photocell correctly for light of colour temperature 6000°K. For the 2500°K of the tungsten filament lamps, the matching is imperfect and necessitates a further correction of -2%. This was computed from the data shown in Fig. 3, for which the energy distribution of extra-terrestrial solar radiation is taken from Nicolet (1951).

(iii) A further systematic error in the calibrations, made during the period under discussion, is due to incorrect measurement of the lamp voltage. By an oversight the voltage was measured across the supply leads instead of at the lamp filament, as specified in the N.P.L. standardisation. Fortunately the same leads had been used throughout the period, and a correction of 5% was determined experimentally and applied to all tabulated results.

5. Systematic errors of recording. The corrections considered above are fixed for the particular instruments and the methods of calibration used. The following corrections, though based on specific instrumental and physical factors, are computed from knowledge of the particular local conditions under which the instruments have been exposed, and on the weather at Kew Observatory during the period 1947-51. It would appear permissible, however, to regard the corrected data as representative of similar sites to an accuracy of the order of ±5%, for the same period.

(a) Exposure of the recorder. The instrument is exposed on the south roof of the Observatory, at a point where some 10% of the north sky is obstructed by the Observatory dome. It is calculated that the fraction of the luminous flux from the sky, which is thus prevented from falling on the horizontal opal plate, is only 3%, or on average some 1-2% of the total flux. On many occasions when the sun is shining, back reflection from the dome contributes a compensating 1-2% of the total luminous flux on the instrument. It is therefore concluded that errors from imperfect exposure are only of the order of 1%.

(b) Temperature coefficient of the thread-recorder. Each time the instrument is calibrated, the sensitivity of the thread-recorder galvanometer is also found, and its temperature noted. Subsequent variations of room temperature, in the basement in which it is situated, may cause random errors of 1-2% due to the temperature coefficient of the galvanometer, but any residual systematic errors in mean values of daylight may be neglected.

(c) Temperature coefficient of the photocell. This varies, for the class of cell used, with the external circuit resistance and with the intensity of illumination. With typical working conditions simulated in the laboratory, the coefficient of the cell and filter was found to be -0.3% per 1°C between 0° and 60°C.

The temperature of the cell had not been noted, either during calibration or recording. As a first step to correcting the tabulated mean values, the excess of cell temperature over its surroundings was measured (by thermocouples) during a typical calibration, and during normal recording in various conditions of sky, wind and time of day. Values of room temperature were then extracted for all available calibration records, and cell temperatures pertaining to each calibration during the five year period were estimated.

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From the experimental data obtained during normal recording, it was possible to relate the excess temperature of the cell over its surroundings to the sine of the sun's elevation for cloudless periods, and to equate the cell temperature to that of the surroundings (i.e. screen temperature) for overcast periods. Having drawn diurnal curves for typical cloudless days in each of the four seasons by fixing the maximum excess temperature at 1300 Z and completing the curves with reference to the sun's elevation, and using mean diurnal curves of screen temperature for the overcast days, interpolation could then be made for other cloud conditions.

For the immediate purpose of applying these corrections to hourly means for 10-day periods, the average cloud amount for Kew during daylight hours was found to be 5/8. The interpolated curves of cell temperature for 5/8 cloud were finally compared with the curve of calibration temperatures, and the differences between them, when multiplied by the temperature coefficient, then gave the corrections to apply. These range between -3% and +5% according to time of day and year.

(d) Imperfection of the diffusing plate - deviation from the cosine law. The response of the daylight recorder, to light incident at various angles, depends largely on the nature of the roughened upper surface of the pot opal glass, but partly also on the geometrical layout of the cell, apertures and diaphragm. The response, found by experiment, is represented in Fig. 4 as a percentage of the response given by a perfect receiver, i.e: one conforming to the cosine law. It does not differ significantly between the Mk.I and Mk.II instruments. The errors at grazing incidence amount to some 50%, and lengthy computations were necessary before the basic tabulations could be corrected.

The original tabulations were first analysed into hourly means (for the five years 1947-51) for the first, second and last 10-day period in each month, (i.e: 1st to 10th, 11th to 20th, and 21st to end of month), designated by the headings 0, 1, 2. Each of these hourly means was split into the direct and diffuse components of daylight by assuming, for the purpose in hand, that the relative proportion of these components is the same as for direct and diffuse solar radiation. These latter quantities were available for the same period, being part of the programme of measurements of short wave solar radiation at Kew Observatory.

The relative intensity of diffuse short wave radiation, over the hemisphere, has been investigated for cloudless and overcast skies by Dines and Dines (1927), whose results do not differ significantly, for the present purpose, from the distribution function quoted by Middleton (1952). By graphical integration of the response of the recorder in zones over the whole hemisphere, a total response of 89.7% is obtained for overcast days and 86.3% for cloudless days. Interpolating for the 5/8 cloud of average conditions gives a mean response of 88.6%, involving a correction of 11.4% to the diffuse component of daylight.

Lastly, the mean elevation of the sun was computed for each hour of each 10-day period. The corresponding percentage correction was obtained from the response curve and applied to the direct component of daylight, and recombined with the diffuse component.

6. The corrected hourly means. The total percentage correction for the separate errors (temperature coefficient, cosine law and calibration errors) was finally computed. Table I shows the complete correction table which has been used. It will be seen that, apart from some large percentage corrections to very small hourly means near sunrise and sunset, the figures range between +1% and +10%.

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The corrected hourly means for 10-day periods are presented in Table II. The basic tabulations, from which these means are extracted, are obtained by estimating the mean intensity for the hours in question by placing a graduated transparent scale over the thread-recorder charts. Random errors up to ±10% may, on occasion, be introduced by this procedure, especially on days of broken cloud and rapidly varying intensity. * More generally these errors are around ±5% * , and any residual systematic errors in the means (each based on 50 observations) will be of the order of ±1%. The times given are in G.M.T.

7. The variability of daylight. Provisional uncorrected data, based on the first two years of recording with the Mk.I instrument, have been given by Stagg (1949) in a paper which had a restricted circulation. These may be related to the present data, when all occasions are considered together, by means of the Table I corrections reduced by 3% throughout (i.e. apply +4% for +7%, etc).

The intensity of daylight illumination on a horizontal surface above the earth's atmosphere, depends on the time of day and year, and on the latitude of the observing station. At Kew (latitude 51° 28'N), the intensity attains a value of 121 kilolux at noon, in midsummer. At noon in midwinter, this value falls to only 37 kilolux.

On cloudless days, these extraterrestrial intensities are not exceeded at the ground, but, with small amounts of cloud near but not obstructing the sun, the hourly mean can rise to about 130 kilolux, owing to scattering and reflection at the cloud surfaces. A value of 200 kilolux may be reached for a minute or two, particularly when large Cumulus clouds are present, but this only rarely.

To demonstrate the longer term variability of daylight illumination, the annual totals for the years 1947 to 1951 have been extracted. These corrected totals, in megalux-hours, are compared with values for the years 1947 to 1949 obtained at Plymouth by Atkins and Jenkins (1952), who used a vacuum sodium cell.

	1947	1948	1949	1950	1951
Kew	118	125	114.5	111	109
Plymouth	108	124	121	-	-

The fluctuations of successive 10-day means, for the same hours in Table II, also demonstrate the considerable variations possible, even when five years data are included.

8. Diurnal variations of daylight. In Fig. 5, mean diurnal curves are shown for the months of March, June, September and December, the time-axis having been converted to L.A.T. Also included is a composite curve for the Equinoxes, which has been constructed from two separate curves, based on the values for the 10-day periods Mar. 2 and Sept. 2.

Fig. 6 shows the mean diurnal curves for selected cloudless days, for the same four months. To construct these, the original charts were re-examined and all occasions selected where there was 1/8 cloud or less (and this away from the immediate vicinity of the sun) for at least three consecutive hours. The end hours of these periods were rejected and the remaining hours tabulated under time of day. A correction table, similar in form to Table I, was then constructed and applied to the means for each hour.

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* Footnote: Those estimates, based on trials in which many charts were measured independently by different observers, are due to Mr. R.H. Eldridge.

The same procedure was carried out for overcast days; periods being selected when there were 7/8 cloud or more (the sun itself always obscured) for at least three hours. When the middle hours were tabulated under time of day and the corresponding correction table applied, it became apparent that insufficient data existed for mean diurnal curves to be drawn objectively. The results are therefore included in Table III with the number of occasions contributing to each hourly mean given in parenthesis.

9. Frequency distribution of daylight intensity. The basic tabulations for the four months: March, June, September and December, were reanalysed for the midday hours: (11-12) and (12-13). For each month, the range of hourly values was subdivided into three equal parts. To the lowest range were applied the corrections for overcast days; to the middle range, those of Table I for average days; to the highest range, those for cloudless days. Slight adjustments were necessary to smooth the corrections to hourly values on the borderline between two ranges.

The corrected tabulations were grouped in ranges of 15 kilolux for the midday hours of March, June and September; 10 kilolux ranges being used for December because of the concentration of these observations into the lowest ranges. Histograms representing the frequency distribution of intensiites, thus found, are shown in Fig. 7.

10. Luminous efficiency of daylight. While daylight is being recorded in the manner outlined above, a nearby Moll solarimeter is simultaneously recording "total" solar radiation in the waveband 0.3μ to about 3.0μ, as described by Stagg (1950). When the ratio, daylight intensity: radiation intensity is expressed in the form, lumens per watt, it is spoken of as the "luminous efficiency of daylight".

To form estimates of this quantity, values of radiation were extracted for the same occasions with cloudless skies as were considered in section 8. It was found unnecessary to correct these tabulations, since: the systematic errors, present in the calibrations of the daylight recorder, are not encountered in the calibrations of the Moll solarimeter (in situ, against the Ångström pyrheliometer), and the temperature coefficient and cosine law corrections for this particular Moll solarimeter are very nearly equal, and of opposite sign.

The results are given in Table IV, where K stands for values of daylight intensity in kilolux and T for solar radiation intensity in mw/cm^2. The main results may be summarised by giving the mean luminous efficiency for each of the four months (for cloudless days only):

	Mar.	Jun.	Sept.	Dec.	Year
lumens/watt	119.5	130.0	137.5	112.5	128.5
(limits)	(95-132)	(121-144)	(107-152)	(103-149)	(95-152)

There is no reason to suspect these values, for it will be shown in a later paper that the illumination and radiation tabulations satisfy several checks of mutual consistency, but they are higher than those usually quoted. Kimball (1924) found values between 97.5 (solar elevation 22°) and 108.0 (solar elevation 65°), while Atkins and Poole (1936) found 107 lumens/watt when some cloud was also present. On the basis of Nicolet's (1951) data for the spectral distribution of extra-terrestrial solar energy, the luminous efficiency of extra-terrestrial daylight is computed to be 104 lumens/watt. With high water vapour content in the atmosphere, (made effectively still higher for large values of air mass), it is to be expected that infra-red absorption would, in causing depletion of total radiation, lead to greater luminous efficiency.

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This is to some extent supported by Fig. 8 in which the mean efficiencies for the four months have been plotted against the mean water vapour contents for the whole atmosphere. Other features noted in the individual values are the lack of variation of the means with solar elevation but the much greater scatter for low angles. This suggests that the variations of the degree of atmospheric pollution, on otherwise similar cloudless days, have a large effect on luminous efficiency.

11. Conclusion and suggestions for further work. As far as the preceding data on daylight illumination can be applied to similar sites, it is thought that the corrected means are within ±5% of the true values. The limited data available for selected overcast and cloudless days are more subject to sampling errors although the qualitative relations can be regarded as fairly representative. In particular, the nearness of the site to the smoke pollution source of the Greater London area often affects the data for cloudless (and frequently calm) days.

The instruments and recording details can clearly be improved. Among projected modifications can be mentioned the installation of a smaller diffusing plate more in keeping with the cosine law, and the thermostatic control of the photocell temperature.

12. Acknowledgments. I wish to express my thanks to Dr. G.D. Robinson for his guidance throughout the investigation, and in particular for checking the mutual consistency of the daylight illumination measurements with those of the other short wave solar radiation components which are measured at Kew Observatory. Thanks are also due to Mr. D.B.B. Powell for assistance in all stages of the breakdown of the data and investigation of instrumental errors, and to Mr. J. MacDowall for help in estimating certain errors in calibration and of exposure.

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Table I.

Percentage correction added to original 5-year mean Daylight Tabulations

		4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20
J	0					6	4	4	5	5	4	4	6				
	1					5	6	6	7	6	6	6	4				
	2					4	3	6	5	4	6	6	5				
F	0				10	6	6	5	5	7	6	8	8	10			
	1				10	10	5	6	5	7	7	6	9	11			
	2				6	6	4	4	5	5	5	5	7	6			
M	0			8	7	7	4	5	6	5	7	5	8	6	1		
	1			10	5	5	4	4	5	5	5	6	6	7	9		
	2			8	6	6	3	4	3	3	5	4	6	8	7		
A	0		10	10	7	6	4	3	4	4	4	5	6	7	10	2	
	1		9	8	7	4	3	5	3	3	5	4	6	8	8	10	
	2		11	8	6	5	4	2	3	3	4	5	8	7	10	9	
M	0	16	9	8	7	6	6	4	3	3	5	7	8	9	12	10	3
	1	10	8	7	7	4	3	3	3	3	5	5	7	9	10	10	3
	2	10	7	7	5	5	3	2	3	3	4	5	6	7	10	8	10
J	0	10	9	8	4	4	2	2	3	3	3	4	6	7	10	9	10
	1	8	7	8	4	4	3	2	3	3	3	4	7	7	9	9	10
	2	11	7	7	4	3	3	2	3	3	3	4	7	7	9	10	10
J	0	6	6	6	4	1	2	1	2	2	2	3	5	5	9	9	8
	1	9	6	7	4	3	1	1	2	3	3	4	5	6	7	6	8
	2	10	8	6	6	2	1	1	2	2	2	3	5	8	8	10	4
A	0	0	7	6	5	4	2	2	2	2	4	2	6	7	9	9	1
	1		8	9	6	4	3	2	3	3	3	4	6	7	10	9	
	2		9	7	7	4	3	2	2	2	3	4	6	9	9	10	
S	0		13	9	6	6	6	3	2	2	5	6	7	7	9	12	
	1		0	5	8	6	5	3	5	5	4	6	8	9	8		
	2			7	8	7	7	5	5	5	6	8	9	9	10		
O	0			14	7	6	5	4	5	5	6	7	8	9	2		
	1				7	8	7	5	7	6	6	7	9	8			
	2				6	6	5	5	5	5	6	9	9	16			
N	0				8	9	9	7	8	8	7	9	7	9			
	1				16	6	5	6	6	6	8	6	5				
	2					9	6	8	6	7	8	8	7				
D	0					7	4	5	6	7	6	5	7				
	1					2	3	5	6	6	5	6	6				
	2					14	5	5	6	6	6	4	8				

Table II.

Corrected hourly means of Daylight Illumination (kilolux-hours) for 10-day periods.

		4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20
J	0					1.6	5.6	9.7	12.1	12.2	9.1	4.9	1.7	Tr			
	1					1.9	7.1	11.6	15.1	13.6	10.8	6.9	2.8	Tr			
	2				Tr	2.3	6.4	11.4	14.9	14.2	11.7	8.1	3.9	0.5			
F	0				0.3	3.2	8.3	13.2	14.9	16.5	15.4	10.1	5.1	1.3	Tr		
	1				1.0	5.9	11.1	18.9	20.8	20.3	18.2	13.7	8.5	3.0	Tr		
	2			Tr	2.4	8.7	16.6	23.7	23.6	26.1	22.8	19.7	12.7	4.7	0.4		
M	0			0.2	3.9	9.9	16.0	22.8	27.7	27.6	25.2	18.8	13.3	5.8	1.0		
	1			1.6	7.1	15.0	23.0	28.7	30.0	33.2	26.9	23.6	17.0	9.4	2.4	Tr	
	2		Tr	3.3	11.6	21.0	27.1	34.0	36.0	37.3	33.6	28.5	20.8	12.3	3.7	Tr	
A	0		0.8	7.6	19.8	33.2	38.4	42.7	50.0	47.3	42.4	31.8	26.9	16.8	7.2	0.7	
	1		2.3	11.0	23.4	35.9	45.6	55.9	59.2	60.3	55.4	44.3	35.7	22.4	9.9	2.4	
	2	Tr	4.1	13.3	27.6	40.4	52.6	58.3	62.3	58.7	57.1	48.8	36.7	25.0	11.2	2.9	
M	0	0.4	4.7	13.1	22.3	30.2	41.2	50.9	52.0	50.6	50.4	45.9	37.6	28.3	15.7	5.3	0.1
	1	1.0	7.7	18.2	30.1	41.7	50.5	61.9	62.1	57.7	58.0	48.1	37.2	26.6	17.5	5.7	0.5
	2	1.8	7.5	16.8	28.9	40.7	47.4	54.2	56.4	59.6	55.7	48.8	40.7	28.5	18.5	7.3	1.7
J	0	3.4	13.8	27.4	38.5	52.5	62.7	73.8	75.7	79.1	71.6	64.0	52.0	37.9	24.6	10.3	2.7
	1	3.4	11.1	25.7	37.2	50.5	56.9	63.4	63.8	63.6	63.4	58.8	49.6	39.2	24.0	11.5	3.6
	2	3.1	11.7	22.9	34.9	48.6	57.6	64.0	66.4	67.5	65.7	63.8	50.1	38.2	23.1	11.1	3.1
J	0	2.7	10.7	21.5	37.2	45.0	58.1	61.2	65.7	63.7	60.8	52.8	43.8	31.3	21.9	10.7	3.2
	1	1.8	8.9	20.0	36.3	42.5	54.3	61.9	71.0	64.0	59.2	52.3	42.2	30.6	21.2	8.9	2.5
	2	1.3	8.8	21.0	37.5	46.6	58.1	67.4	71.6	72.4	69.9	58.7	46.0	34.8	22.9	10.0	2.3
A	0	Tr	5.9	16.9	28.4	40.6	49.0	57.5	63.0	61.8	63.0	52.6	42.6	30.4	19.0	8.3	0.7
	1	Tr	4.7	16.2	30.7	45.1	57.2	65.5	68.0	68.9	63.7	53.4	43.3	29.2	16.5	5.6	0.1
	2		2.5	11.8	26.0	41.1	53.8	58.0	63.5	62.6	59.9	47.0	37.4	26.6	13.5	3.1	
S	0		1.0	8.6	21.2	35.8	47.4	55.4	61.4	56.4	53.9	44.2	33.7	17.7	7.6	0.8	
	1		0.3	6.4	18.1	30.9	39.8	46.5	47.7	47.5	43.9	36.7	27.5	15.4	5.2	Tr	
	2		Tr	4.0	13.1	25.0	34.2	41.7	45.1	44.3	39.2	34.0	23.0	10.1	2.5		
O	0			1.7	7.5	17.2	26.7	36.6	39.3	39.3	37.5	26.1	15.2	6.0	0.4		
	1			0.9	6.0	14.3	23.7	26.8	33.2	31.0	26.3	17.8	10.9	3.3	Tr		
	2			Tr	3.2	9.2	14.4	20.5	24.1	24.1	19.6	13.9	6.6	1.2			
N	0			Tr	2.2	8.3	14.8	20.3	22.8	21.5	17.6	10.7	4.4	0.2			
	1				1.1	6.1	12.4	18.0	19.3	18.7	14.7	8.5	2.9	Tr			
	2				0.2	3.8	8.0	13.0	15.6	14.6	10.9	5.5	1.7	Tr			
D	0				Tr	2.2	6.4	9.9	11.2	12.0	8.9	5.0	1.3	Tr			
	1					1.6	5.5	9.6	12.1	11.1	8.0	4.9	1.2	Tr			
	2					1.4	4.4	7.9	10.1	10.6	7.8	4.4	1.2	Tr			

Table III.

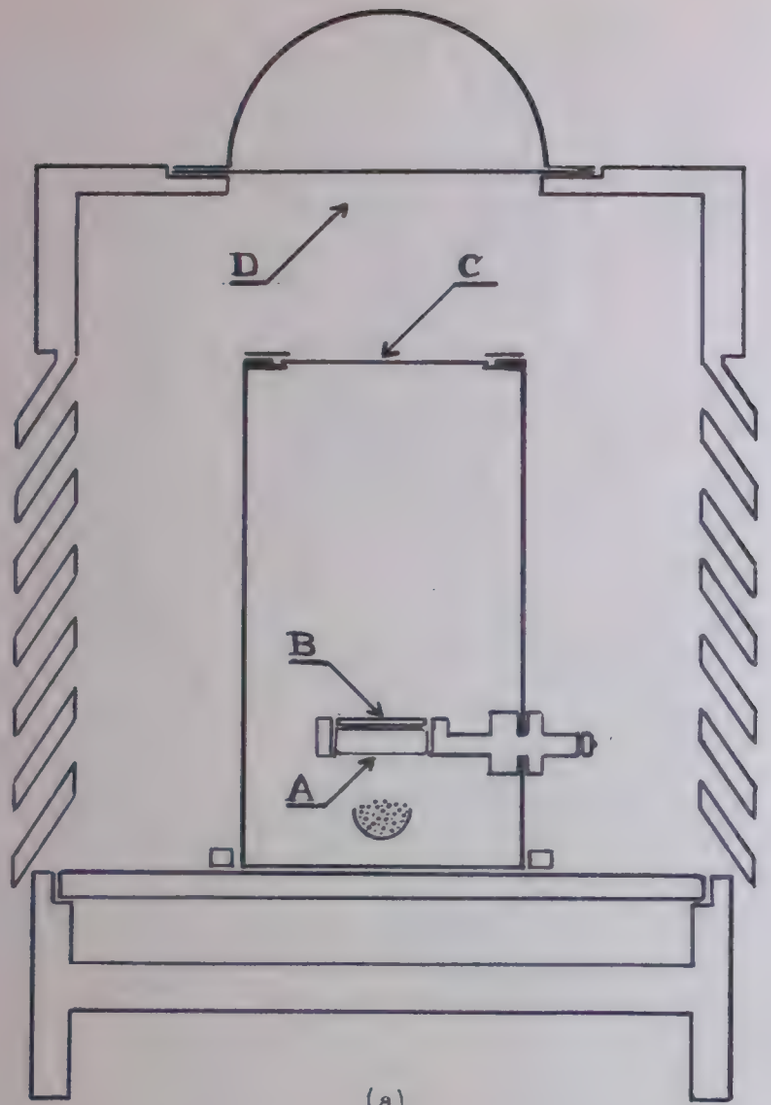
Diurnal variation of Daylight Illumination (kilolux-hours) on overcast days

		5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19
Mar.			-	-	8½	6½	7½	10	9	9	9	11	6	-	
			-	-	(2)	(1)	(1)	(14)	(14)	(17)	(19)	(9)	(1)	-	
June		-	8	13	-	-	-	11	15	20½	11	12	8	4½	-
		-	(10)	(7)	-	-	-	(1)	(1)	(1)	(1)	(2)	(3)	(2)	-
Sep.			-	9	-	-	22	17½	16	17½	15	12	9	-	
			-	(5)	-	-	(2)	(10)	(9)	(8)	(12)	(9)	(1)	-	
Dec.					-	-	-	5½	6	5	-	-			
					-	-	-	(17)	(22)	(21)	-	-			

Table IV.

Luminous efficiency of Daylight (lumens/watt) on cloudless days

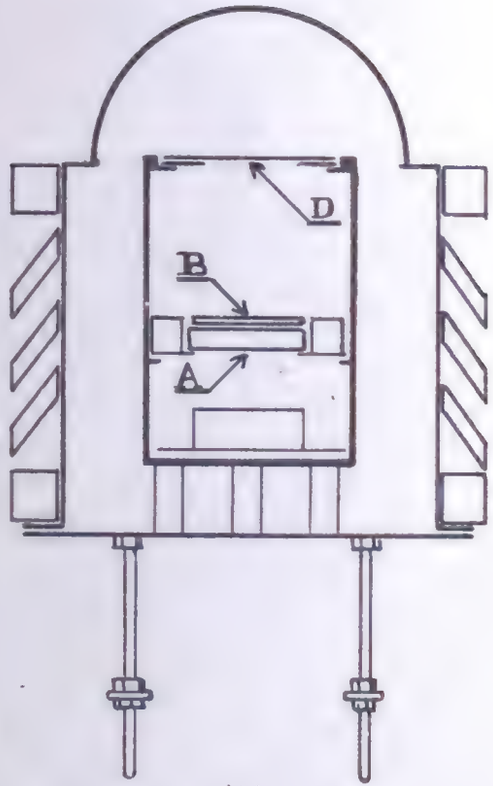
Mar.	K		-	15	26	-	-	65	64	61	46	36	20	-	
	T		-	15½	27½	-	-	51	52½	47½	39½	27½	18	-	
	K/T		-	96	95	-	-	127	122	128	116	132	111	-	
June	K	21	31	51	74	86	48	103	105	98	86	72	58	41	20
	T	15	25½	40	56	67½	75½	82	82½	74½	65	56	43	28½	15½
	K/T	139	121	125	133	128	130	125	127	132	132	129	135	144	128
Sep.	K		-	24	41	-	-	90	90	76	55	36	-	-	
	T		-	20	35	-	-	61½	60	50	40	33½	-	-	
	K/T		-	121	118	-	-	146	150	152	137	107	-	-	
Dec.	K				-	-	20	-	20	15	13	-			
	T				-	-	18	-	19	14½	8½	-			
	K/T				-	-	111	-	104	103	149	-			



(a)

Mark I instrument

1/4 Scale



(b)

Mark II instrument

Fig.1

A. Selenium photocell.
B. Filter.
C. Clear glass cover.
D. Opal diffusing glass.

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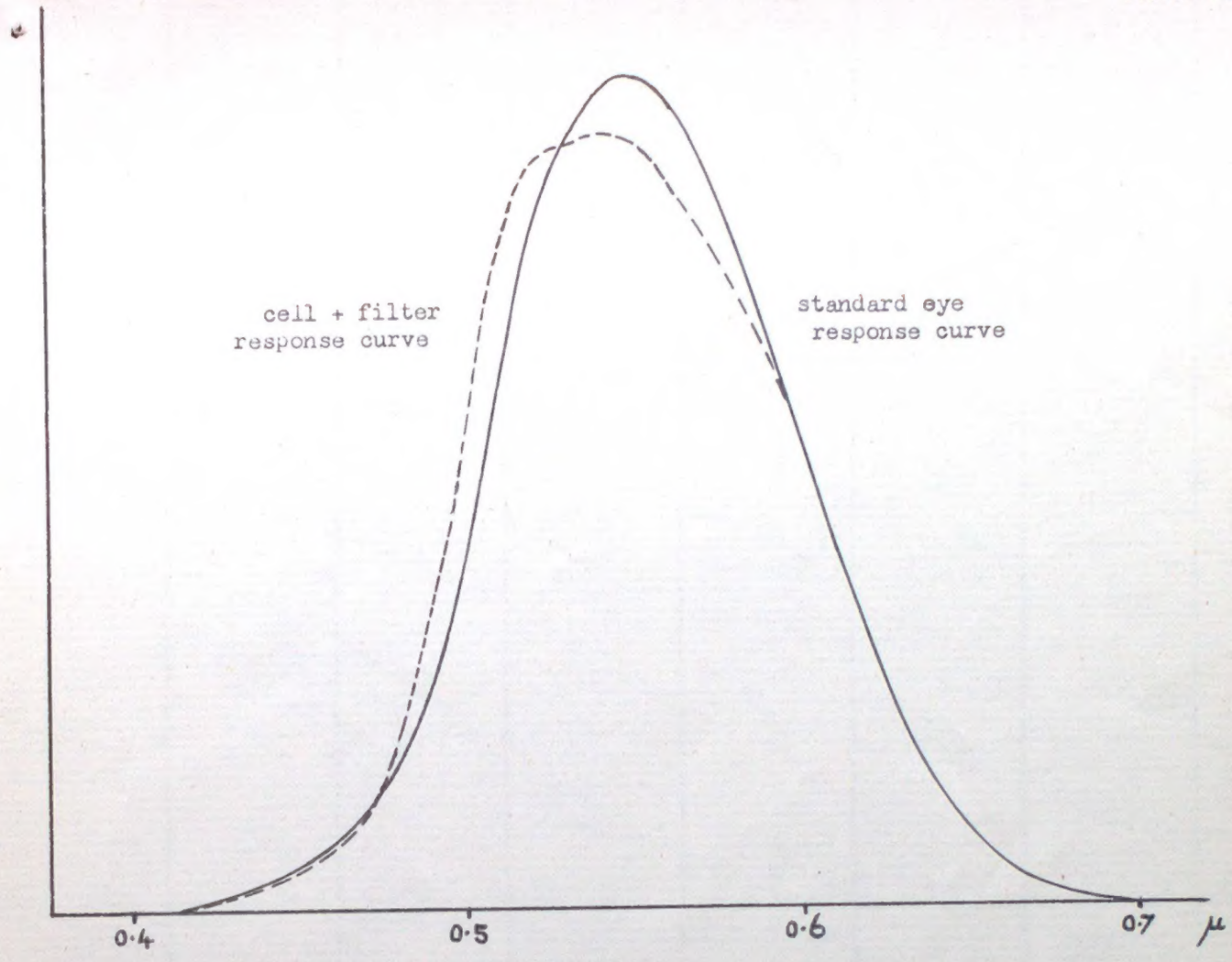

Fig.2 - Relative spectral sensitivity curves of cell + filter and standard eye.

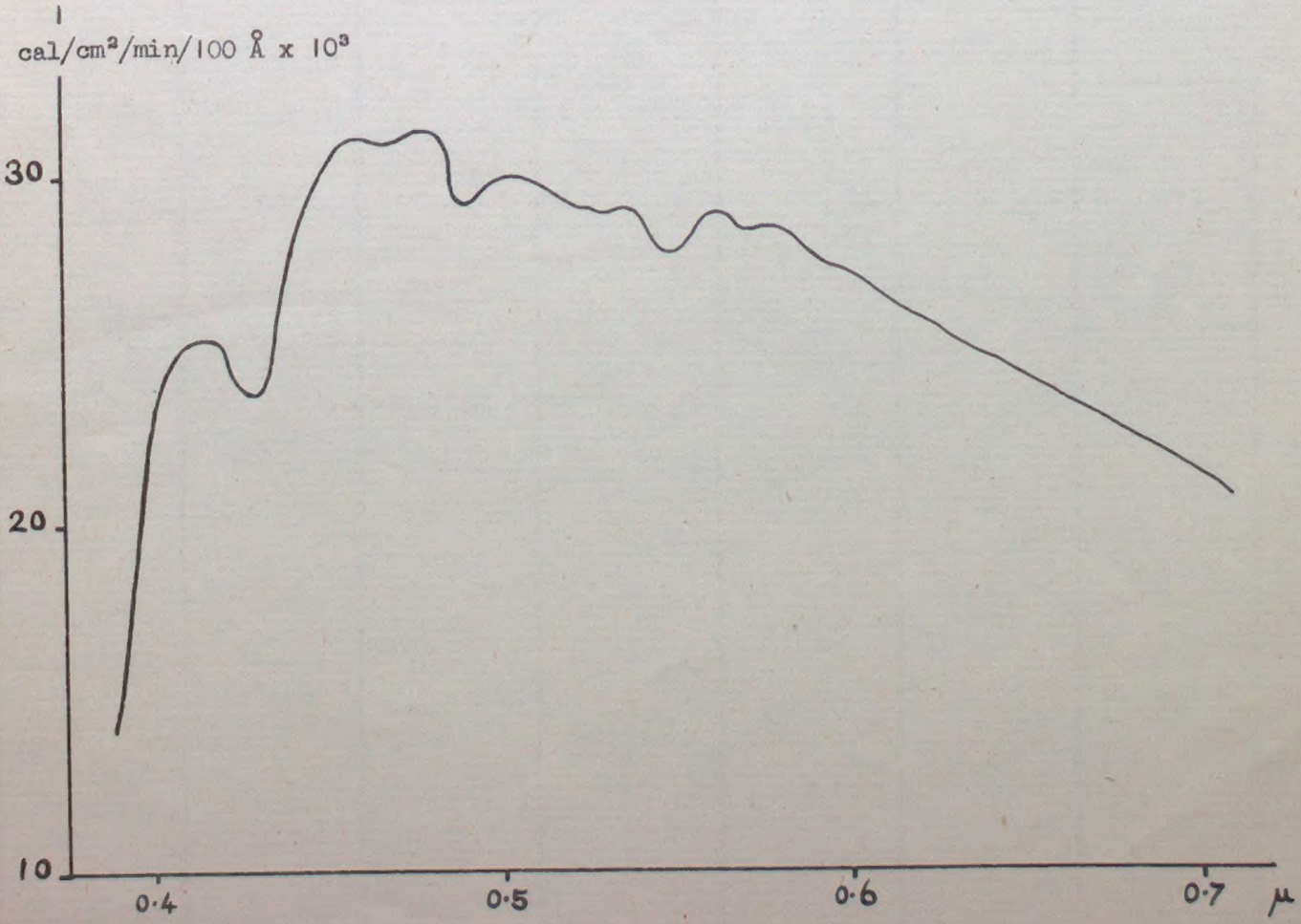

Fig.3 - Spectral distribution of extra-terrestrial solar radiation (after Nicolet).

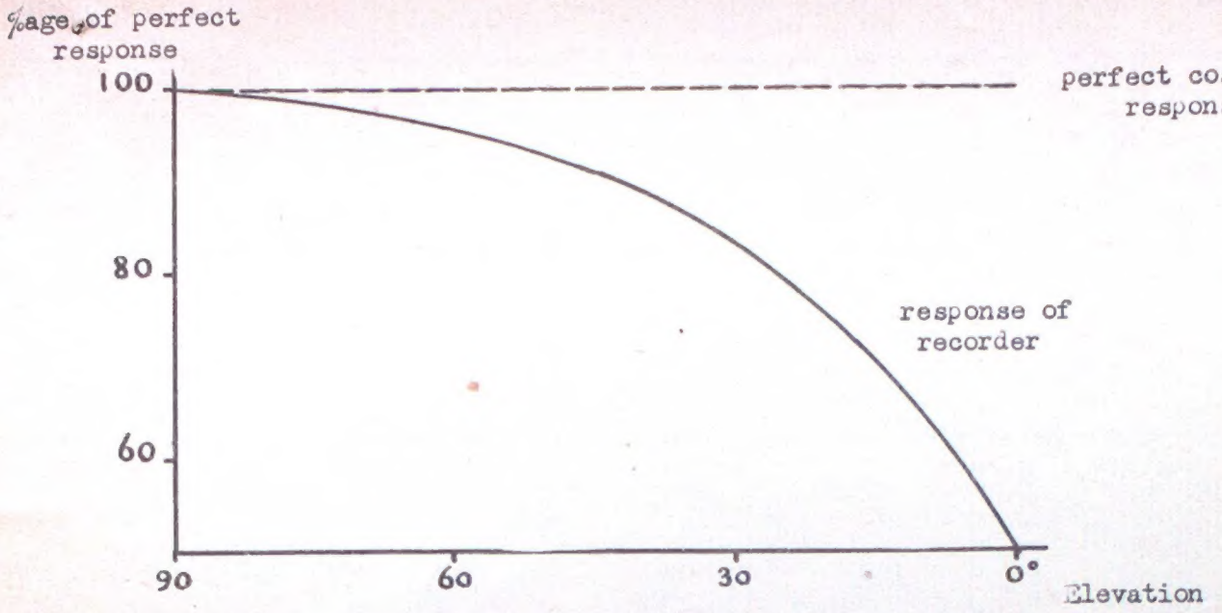

Fig.4 - Departure of response of daylight recorder from cosine law.

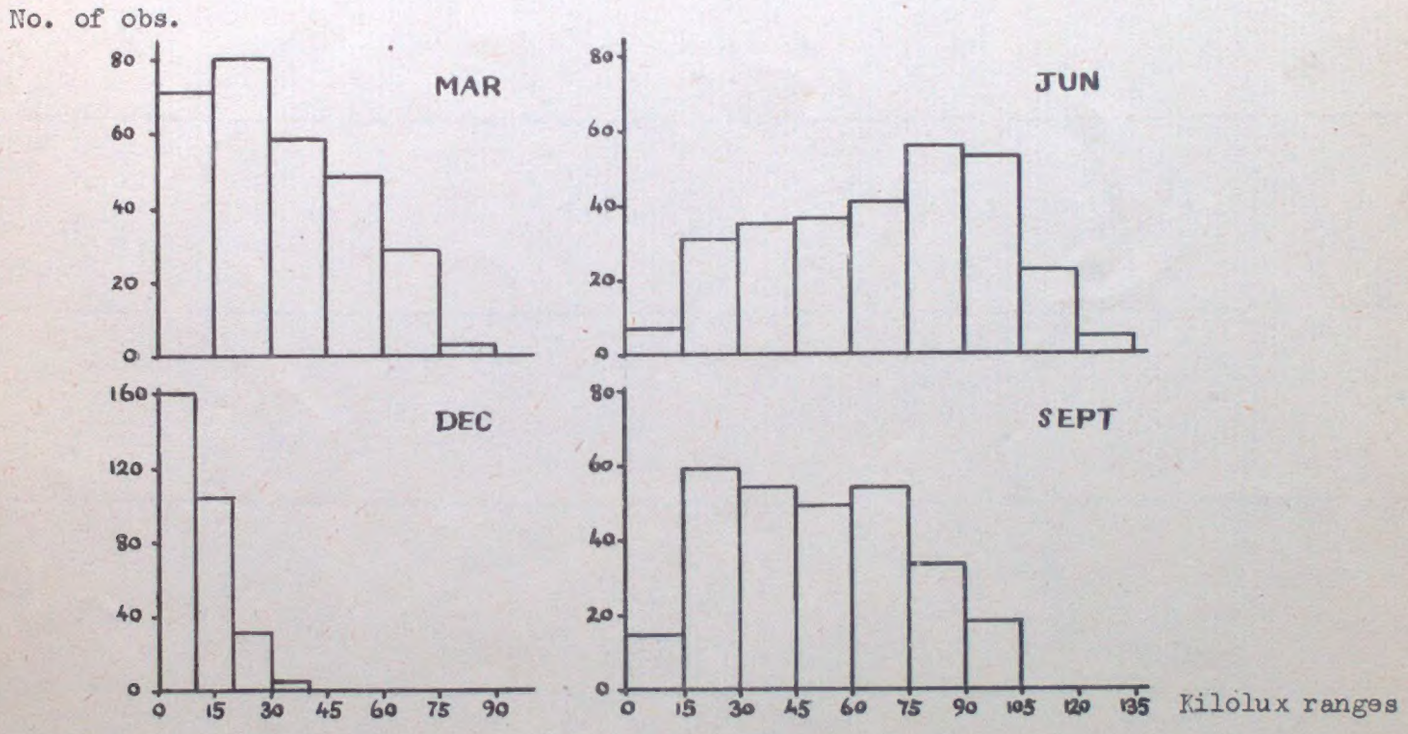

Fig.7 - Frequency distribution of daylight intensity at midday.

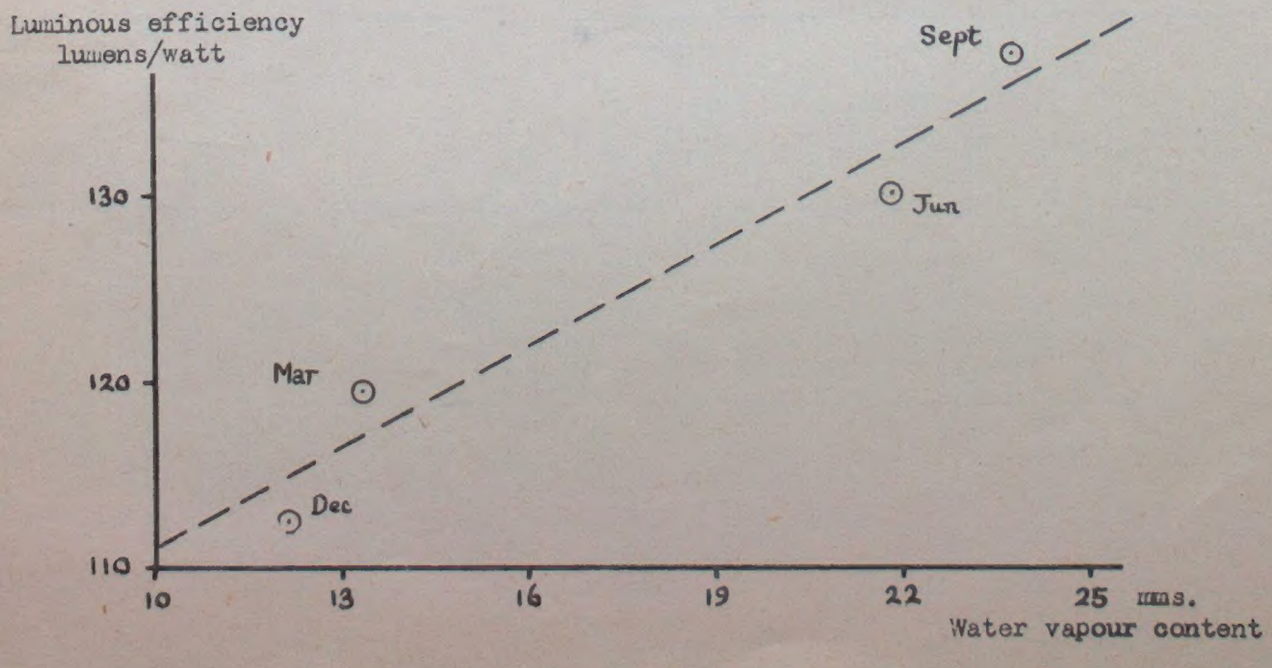

Fig.8 - Relation between luminous efficiency and water vapour content of the atmosphere.

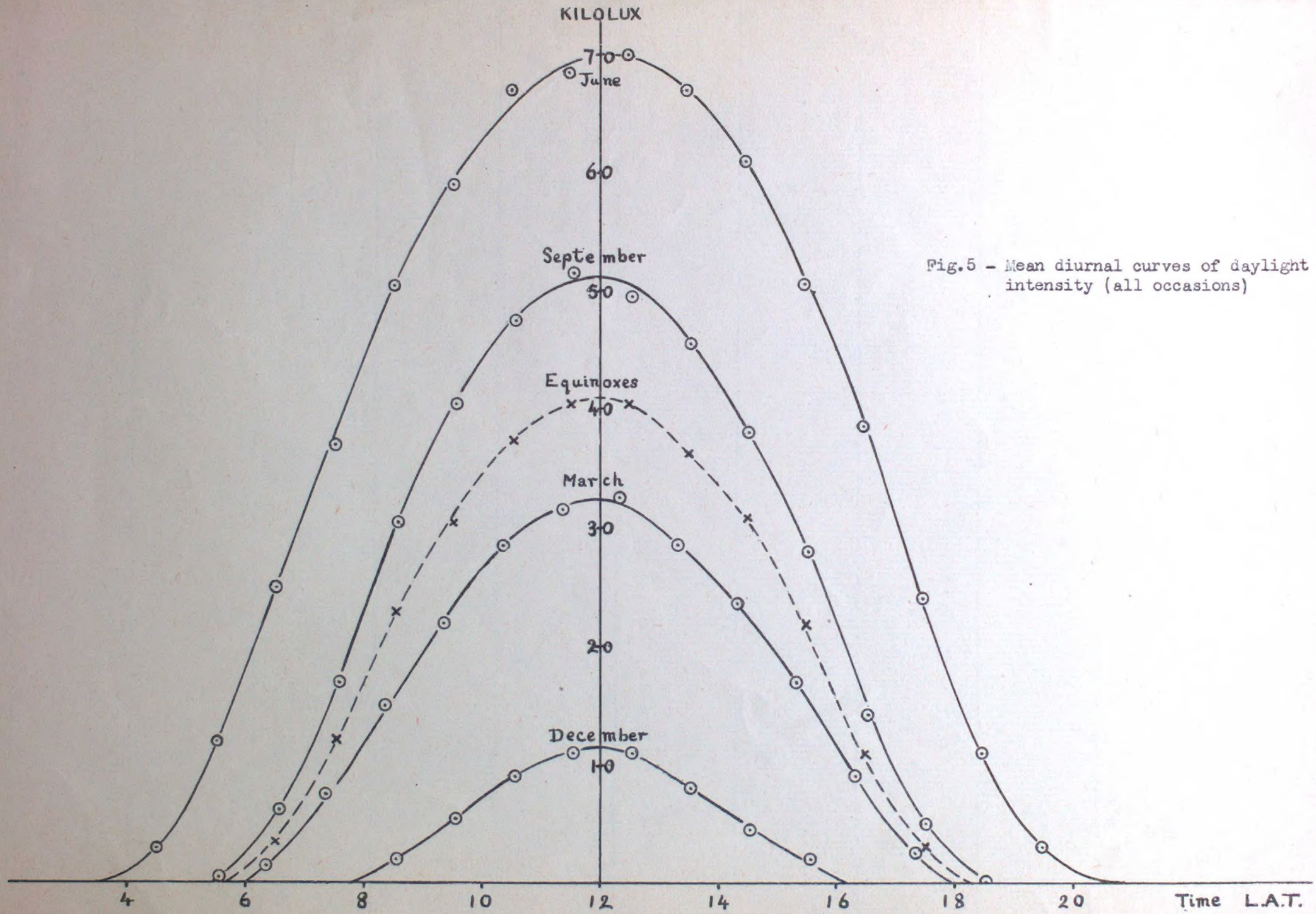

Fig.5 – Mean diurnal curves of daylight intensity (all occasions)

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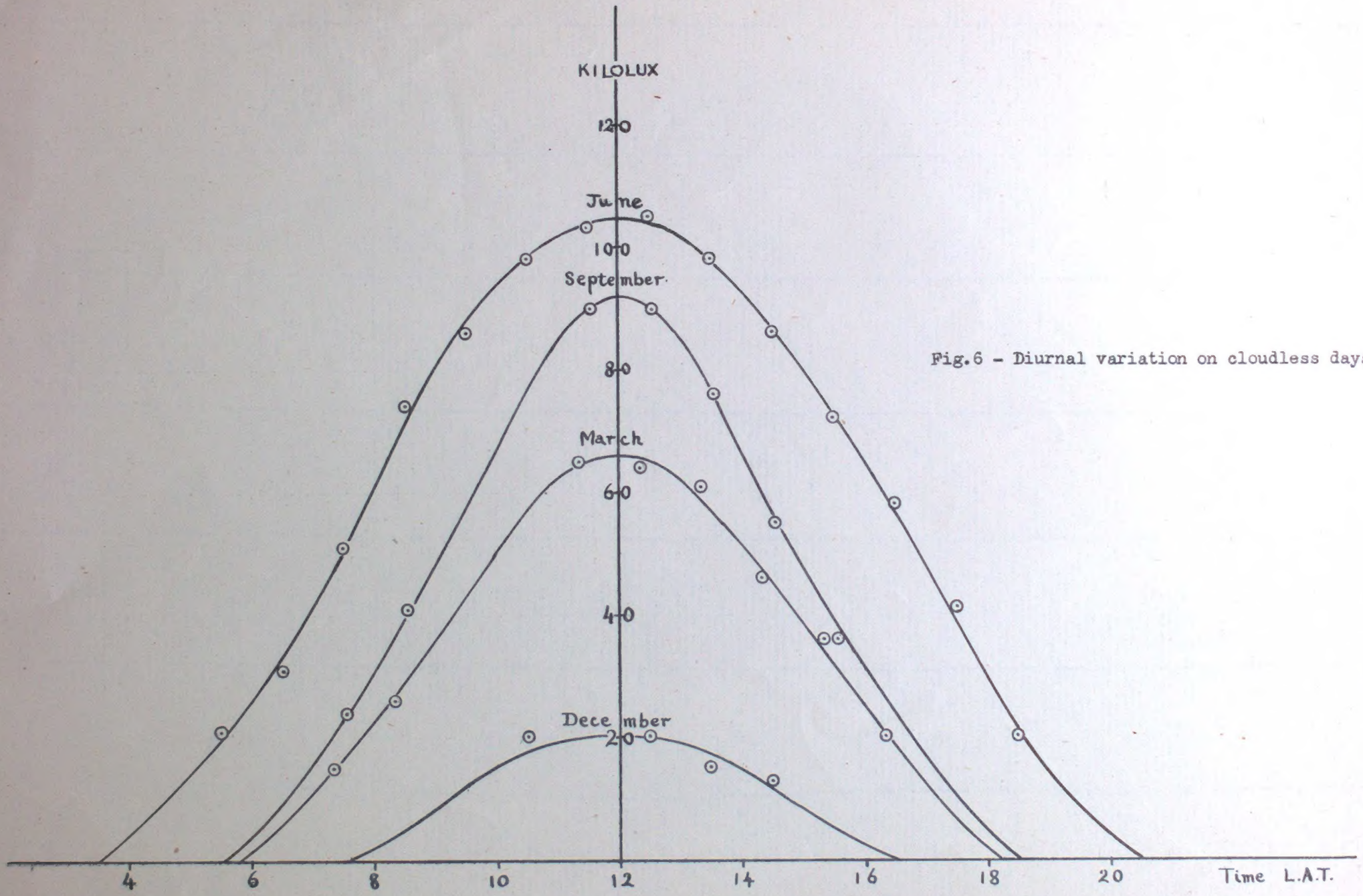

Fig.6 - Diurnal variation on cloudless days.

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